Philosophical Magazine Series 6

ISSN: 1941-5982 (Print) 1941-5990 (Online) Journal homepage: http://www.tandfonline.com/loi/tphm17

LIV. Positive rays

J.J. Thomson M.A. F.R.S.

To cite this article: J.J. Thomson M.A. F.R.S. (1908) LIV. Positive rays , Philosophical Magazine Series 6, 16:94, 657-691, DOI: 10.1080/14786441008636543

To link to this article: http://dx.doi.org/10.1080/14786441008636543

So far as the commercial services are concerned, the possibility of transmitting messages to one station without affecting the others, results in the stations having an increased working capacity and consequently in an enhancement of their commercial value. The ability to receive from one determined direction renders the receiving station independent of extraneous transmissions, and even owing to this circumstance alone the working capacity of the stations is raised. Further, the ability to determine the origin of a transmission, apart from its obvious advantages, presents the advantage of enabling the route to be followed by a ship proceeding to the assistance of another in danger, to be indicated.

From the strategic point of view the directive reception enables one to learn of the presence of the enemy in a certain direction and to follow him in his movements. The directive transmission will allow, when suitably employed, of transmitting to one's friends without the enemy being able to receive the waves—for the simple reason that there are no waves there to be detected in the undesired region.

In conclusion, the following is given as one practical example of the main strategical advantage of the directive system. Supposing it were necessary to send radiotelegraphic messages to the cruiser squadrons on the north-east, north, north-west, and west coasts of the United Kingdom ; if the messages were sent by an ordinary vertical antenna system they would be perceived in Denmark, in Germany, in Belgium, Holland, and France. Employing, on the other hand, the unilateral system, the messages sent from London to the Fleet would not be received outside the United Kingdom.

The authors desire to thank Mr. L. H. Walter for translating this paper from the original.

LIV. *Positive Rays.* *By* J. J. THOMSON, *M.A., F.R.S.; Cavendish Professor of Experimental Physics, Cambridge; Professor of Natural Philosophy at the Royal Institution* *.

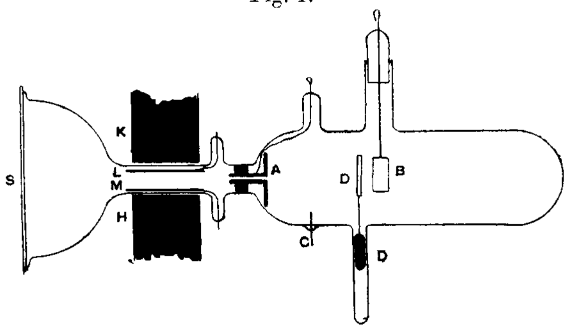
THOUGH the ordinary cathode rays are the most conspicuous of the rays spreading out from the cathode in a vacuum-tube, there are other rays mixed with them, which as Goldstein (*Verhandl. d. Deutsch. physik. Gesellsch.* iv. p. 228, 1902) and the writer (Proc. Camb. Phil. Soc. ix. p. 243) showed long ago are not appreciably deflected by weak magnetic fields. The very complete study of the region near the cathode made by Goldstein, the results of which are

* Communicated by the Author.

described in a paper read before the Physical Society of Berlin (republished Phil. Mag. Mar. 1908), has led him to distinguish five kinds of rays besides the cathode rays. Recent experiments made by Villard (*Comptes Rendus*, cxliii. p. 673, 1906) and the author (Phil. Mag. xiv. p. 359, 1907) have shown that some of these rays are deflected in electric and strong magnetic fields, and the direction of the deflexion indicates that they carry a positive charge of electricity. The fact that these positively charged rays travel with high velocities away from the cathode, and thus against the direction of the electric force, makes the investigation of their properties a very interesting problem, and I have lately made a series of experiments with the object of obtaining some information as to their nature and origin.

The tube used in the first series of experiments is represented in fig. 1. A is a perforated electrode through which

Fig. 1.



rays can pass on their way to the phosphorescent screen S covered with Willemite; the rays on their journey to the screen traverse strong electric and magnetic fields, the former produced by charging the plates L M to different potentials and the latter by placing the tube between the poles of a powerful electromagnet. From the deflexions which these produce on the rays, the velocities and values of e/m for the rays can be determined in the usual way. B is a flat electrode at the other end of the tube; this electrode is carried by a stopper working in a ground-glass joint, and can be rotated about a vertical axis. C is an auxiliary electrode at the side of the tube. D is a side tube in which a metallic obstacle is placed at the end of a rod, this end is fastened to a closed glass vessel containing a piece of iron. By moving this vessel along D by means of a magnet, the obstacle can either be inserted in the line of fire of the rays coming from B and passing down the hole in A, or withdrawn into the tube; the obstacle is in metallic connexion with a wire leading out of the tube, so that it can be used as a cathode if required. The discharge through the tube was produced in some cases by a large induction-coil, in others by a Wimshurst machine.

If the stopper carrying the electrode B was turned so that the normal to the electrode coincided with the axis of the tube A, or made only a small angle with it, and if B were made cathode and a discharge sent through the tube, then in addition to the cathode rays other rays passed through the tube in A and excited phosphorescence on the screen. The direction of the deflexions of the phosphorescence under electric and magnetic forces showed that these rays were charged with positive electricity.

If A were made cathode, the ordinary Canalstrahlen produced bright phosphoresence on the screen. The first point investigated was to make sure that the positive rays observed when A was anode, were not due to reversals of the induction-coil making A at times a cathode and sending ordinary Canalstrahlen down the tube. Very simple observations, however, showed that this could not be the explanation. In the first place, the positive rays still passed down the tube when A was disconnected from the coil and the auxiliary electrode C used as an anode; secondly, A being connected with the coil, the rays down the tube disappeared when B was twisted round, so that the normal to its plane made a considerable angle with the axis of the tube; and thirdly, the rays down the tube were stopped when the obstacle in the side tube was pushed forward so as to be in the line between the cathode and the aperture in the anode.

The next point investigated was to see whether the effect might not be due to A acting at times as a cathode in virtue of the negative charge given up to it by the cathode rays starting from B. That this is not the explanation is proved by the following experiments. When the cathode rays were diverted by a magnet so that they no longer fell upon A, the brightness of the phosphorescent patch due to the positive rays going down the tube in A was not appreciably diminished, although the tendency for A to become cathode must have been almost entirely removed. The conclusions drawn from this experiment were confirmed by the results obtained when the obstacle in the side tube was used as a cathode instead of B. When the obstacle was not pushed far enough across the tube for its normal to pass down the tube in A, no positive rays passed down the tube, but as soon as the obstacle had advanced into such a position that its normal went down the aperture in A, the phosphorescence on the screen due to the positive rays appeared. The contrast between the brightness of the phosphorescence when the normal to the obstacle went down the hole in A and when it did not was very sharp, though there was very little variation in the number of cathode rays striking against the anode as a whole. These experiments show that the positive rays under discussion are not due to reversals of the induction-coil nor to the negative electrification of A by the bombardment of cathode rays, but that they originate at the cathode and travel away from it down the tube.

By means of the rotating cathode B we can determine whether the positive rays coming from the cathode are emitted normally to its surface, or whether, like some of the rays observed by Goldstein, they come off in all directions. When the normal to the cathode went down the tube in A, a plentiful supply of positive rays went down the tube. When the cathode was rotated, the phosphorescence due to the positive rays did not immediately disappear, although it became very much fainter; it could, however, be detected until the normal to the cathode made an angle of about 15° with the axis of the tube. The positive rays under discussion appear to follow much the same path as the cathode rays, for it was found that the angle of rotation required to prevent these getting down the tube was much the same as that required to extinguish the phosphorescence due to the positive rays.

Properties of these Positive Rays.

These rays get exceedingly faint at very low pressures, and cease to be observable at pressures when the Canalstrahlen are still quite bright. It is probably due to this that I have never been able to observe the resolution of the phosphorescence, under the action of electric and magnetic forces, into separate patches as in the case of Canalstrahlen (Phil. Mag. xiii. p. 561, 1907) when the pressure is low. The spot of phosphorescence due to the positive rays coming out in front of the cathode is, under the action of electric and magnetic deflexion of the rays, drawn out into a continuous band, even when the pressure is such that the phosphorescence due to the Canalstrahlen shows well-developed patches. In the case of the Canalstrahlen, there are some rays whose deflexion shows that they are negatively charged and have a mass comparable with that of the positive rays. We find, too, in the case of the rays travelling in the opposite direction to the Canalstrahlen, that a considerable number of them are negatively charged particles, indeed I think the proportion of the negative to the positive is greater in this case than in that of the Canalstrahlen. I have observed cases in which the phosphorescence due to the negatively charged particles was little, if at all, less than that due to the positively charged ones.

A large number of determinations were made, by the method described in my first paper (Phil. Mag. xiii. p. 561, 1907), of the velocity and values of e/m for these rays; in consequence of the spot of phosphorescence being drawn out into a band, the values of e/m ranged continuously from 0 to a maximum value.

Two tubes were used for this purpose, in one of them (fig. 1) the electrode B was connected with a stopper ground into the tube, one side of the electrode was aluminium, the other calcium; by turning the stopper either side could be made to face the tube A, down which the rays passed. L M are parallel plates, which can be connected with a battery of storage-cells; when this is done rays passing between the plates are acted on by a strong electric field. S is the screen at the end of the tube. H, K the pole-pieces of the electro-magnets. C is a wire fused into the tube, to serve as an electrode, thus allowing A to be insulated or connected with one or other of the electrodes at will. The dimensions of the parts of the tube which affect the deflexions of the phosphorescence are as follows:—

Distance between the plates L and M $= \cdot 45$ cm.
Length of these plates . . . . $= 3\cdot 8$ cm.
Distance between the screen and the end of the plates . . . . . . $= 4\cdot 0$ cm.

If V is the potential in volts between the plates, e the charge, m the mass, and v the velocity of the rays, D the deflexion due to the electrostatic field, we can easily prove that

$$\frac{e}{mv^2} = \frac{D}{5 \times 10^9 V}.$$

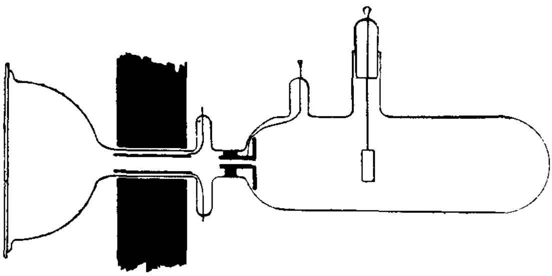
While if d is the deflexion due to the magnetic field when a current of 1 ampere is passing through the coils, it was found by the method described in Phil. Mag. xiii. p. 561, that

$$\frac{e}{mv} = \frac{d}{2\cdot 8 \times 10^4}.$$

From these equations the following determinations of e/m and v were made; the value of V was 420 volts.

Tube filled with Air.			
D.	*d.*	e/m.	v.
·5	1·4	10^4	2×10^8 cm./sec.
·4	1·1	$\cdot78\times10^4$	2×10^8 ,,
·5	1·4	10^4	2×10^8 ,,
·45	1·3	$\cdot96\times10^4$	$2\cdot1\times10^8$,,
·4	1·4	$1\cdot25\times10^4$	$2\cdot5\times10^8$,,
·4	1·3	$1\cdot08\times10^4$	$2\cdot3\times10^8$,,
·3	1·1	$1\cdot04\times10^4$	$2\cdot6\times10^8$,,
	Mean ...... $1\cdot01\times10^4$		
	Tube filled with Hydrogen.		
·7	1·7	$1\cdot05\times10^4$	$1\cdot8\times10^8$ cm./sec.
·4	1·3	$1\cdot08\times10^4$	$2\cdot3\times10^8$,,
·6	1·5	$\cdot96\times10^4$	$1\cdot7\times10^8$,,
·4	1·3	$1\cdot08\times10^4$	$2\cdot3\times10^8$,,
	Mean ...... $1\cdot04\times10^4$		

Fig. 2.



The other type of tube (fig. 2), in which there were no auxiliary electrodes, had the following dimensions :—

Distance between the plates L and M = ·4 cm.
Length of plates . . . . = 4 cm.
Distance between screen and plate = 3·5 cm.

Hence if V is the potential-difference in volts between the plates, and D, as before, the deflexion in the electrostatic field,

$$\frac{e}{mv^2}=\frac{\mathrm{D}}{5\cdot5\times10^9\mathrm{V}}.$$

The magnet had been readjusted and furnished with new pole-pieces. If d was the magnetic deflexion, it was found that when 1 ampere was the current through the coils

$$\frac{e}{mv}=\frac{d}{4\cdot5\times10^4}.$$

With this tube the following values of e/m and v were obtained for the positive rays proceeding from the cathode in the opposite direction to the Canalstrahlen. The value of V was 400 volts.

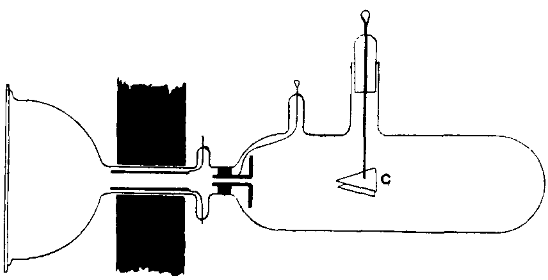
Tube filled with Air.			
D.	*d.*	*e/m.*	*v.*
·4	1·7	$\cdot83\times10^4$	$2\cdot2\times10^8$ cm./sec.
·3	1·6	$\cdot9\times10^4$	$2\cdot6\times10^8$,,
·5	1·9	$\cdot72\times10^4$	$1\cdot7\times10^8$,,
·5	2·0	$\cdot9\times10^4$	$2\cdot0\times10^8$,,
·4	1·8	$\cdot9\times10^4$	$2\cdot2\times10^8$,,
·2	1·3	$\cdot9\times10^4$	$3\cdot2\times10^8$,,
·4	1·7	$\cdot83\times10^4$	$2\cdot2\times10^8$,,
Mean		$\cdot85\times10^4$	
Tube filled with Helium.			
·5	20	$\cdot9\times10^4$	$2\cdot0\times10^8$ cm./sec.
·5	22	$1\cdot08\times10^4$	$2\cdot2\times10^8$,,
·5	21	1×10^4	$2\cdot1\times10^8$,,
Mean		$\cdot99\times10^4$	

The deflexions of the Canalstrahlen in the same tube were also observed: this could easily be done by making the tube A the cathode. It was found that the structure of the Canalstrahlen was more complicated than that of the retrograde positive rays, the former showing two types of rays, characterized by values of e/m in the ratio of 2 to 1: the latter showed only one type of ray, this type coinciding, however, both as to value of e/m and the velocity with the type of Canalstrahlen rays having the maximum value of e/m. Some of the retrograde rays, as well as some of the Canalstrahlen, are deflected in a direction which shows that they carry a negative charge, and that their mass is comparable with that of the positively charged particles. I have determined the value of e/m and the velocity of these negative constituents of the retrograde rays, and find that the value of e/m for the negative particles is numerically equal to that of e/m for the positive ones; while the velocity of the negative ones is slightly, but only slightly (about 15 per cent. in my experiments), less than that of the positive ones.

Experiments with Goldstein's Double Cathodes.

Goldstein (*loc. cit.*) found that when the cathode consists of two parallel plates in metallic connexion, rays other than the cathode rays proceed from the space between the plates. If the plates are triangles, Goldstein found that a pencil of easily deflected cathode rays start from the middle points

Fig. 3.



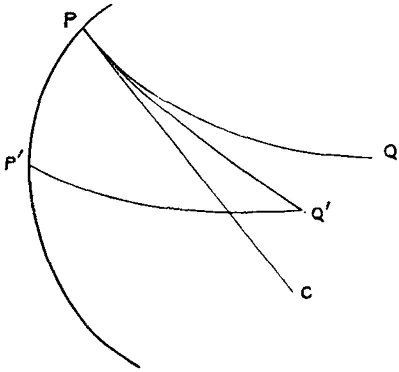
of the sides, while pencils of undeflected rays start from the corners of the triangle. The difference in the character of the rays can be strikingly shown by using helium in the discharge-tube, when the rays from the corners are red and those from the sides blue. I have examined the electric and magnetic deflexion of these rays, using for the purpose a tube such as that shown in fig. 3.

The cathode consists of two parallel triangles, and is carried by a stopper working in a ground-glass tube. By turning the stopper the different parts of the triangular cathode could be brought opposite to the opening in the tube and the distribution of the rays round the triangle studied. I found that this distribution depended a good deal upon the pressure of the gas in the discharge-tube. At all the pressures I tried, I found that the maximum emission of ordinary cathode rays was along the line starting from the middle points of the sides; at the higher pressures, this was the only direction in which the cathode rays could be detected; at very low pressures, however, rays could be detected starting from the corners of the triangle as well as from the middle points of the sides, few, if any, however, were given out in any intermediate position. With regard to the positive rays, I found at all the pressures I tried that these streamed off from both the corners and the middle points of the sides, there were but few in any intermediate position; the most abundant stream came, as was the case for cathode rays, from the middle points of the sides, but the disproportion between the streams from the corners and from the sides was nothing like so great for the positive as it was for the cathode rays; so that the ratio of the quantity of the positive rays to the quantity of cathode rays was greatest at the corners of the triangle.

I also measured the velocity and the value of e/m for the positive rays. I found that this was the same whether the rays came from the corners or from the sides, and the same as that of one type of Canalstrahlen (the type for which $e/m=10^4$), which went down the tube when A was made cathode. In the case of the positive rays coming from the triangular cathode, often only a small fraction were at all affected by electric and magnetic forces, by far the larger portions were quite undeflected by these forces; so that the phosphorescence of the screen when the magnetic force was applied to the tube presented the appearance of a bright central undeflected patch with a faintly luminous tail.

We can, I think, explain this distribution of the rays from the triangular cathode on the view that there is a reciprocity between the cathode rays and the positive rays of the following kind. The corpuscles in the cathode rays are due to the impact of positive ions at or near the cathode, while the positive rays are due to the impact of the corpuscles at some distance from the cathode. Let us consider now what happens when the lines of electric force in the neighbourhood of the cathode are curved as in fig. 4. A corpuscle starting along the normal from P would on account of its inertia not

Fig. 4.



follow the line of force PQ but some path PQ′ between PC and PQ, PC being the normal to the cathode. If, now, the corpuscle produces a positive ion at Q′, this ion as it moves up to the cathode will not follow the path Q′P but some such path as Q′P′, striking the cathode at P′, and producing a cathode ray at P′. Thus the positive particle, if it strikes the cathode at all, will not give rise to a cathode ray to replace the one which produced it, but a ray starting from some other region. If, however, the line of force starting from P were a straight line, the positive particle produced by the ray at P would strike the cathode at P. When the discharge is in a steady state the number of corpuscles coming from *any region* must be proportional to the number of positive particles falling on that region. Now this will be the case when and only (except perhaps in very special cases) when the positive rays which strike the region are those produced by the corpuscles coming from it. For this to happen, the lines of force from that region must be straight lines. In the case of the triangular cathode there are six regions where the lines of force are straight, the middle points of the sides and the corners; and it is therefore from these regions that we should expect the discharge to be concentrated; and inasmuch as the region over which the lines are approximately straight is much greater at the middle points of the sides than at the corners, we should expect the maximum discharge to come from the middle point of the sides.

Magneto-Cathodic Rays.

Among the rays which sometimes occur near the cathode are some observed by Villard (*Comptes Rendus*, cix. p. 42, 1905) and called by him magneto-cathodic rays. These rays occur when the discharge-tube is placed in a strong magnetic field; they are in the direction of the lines of magnetic force, and when subject to an external electric field they are displaced in a direction at right angles to the electric and also to the magnetic force. Ions moving through a medium in which they are under the action of electric and magnetic forces, and which resists their motion with a force proportional to their velocity, would behave exactly in this manner. For, just as a stone falling through a resisting medium moves at first with nearly uniform acceleration but after a time settles down into a state where the velocity is constant and equal to what is known as the limiting velocity, so ions, when exposed to electric and magnetic forces and to a resistance proportional to their velocity, will after a time settle down to a state where the velocity is uniform. The time required to reach this state is inversely proportional to the resistance when the velocity is unity and directly proportional to the mass of the ion. I have shown in my 'Conduction of Electricity through Gases' (2nd edition, p. 106) that when the ions have reached this state, and the magnetic force H is so large that Hu_0 is large compared with unity, u_0 being the velocity acquired by an ion when unit force acts upon it, and inversely proportional to the pressure, then the ions move nearly along the lines of magnetic force, but have a small component in the direction at right angles to both the electric and magnetic forces. In these respects they resemble Villard's magneto-cathodic rays; the ions, however, would carry electric charges, while Villard could detect no charge when the magneto-cathodic rays entered a Faraday cylinder. It is perhaps possible that the absence of charge may have been due to the rays making the gas round the Faraday cylinder so good a conductor of electricity, that no appreciable charge could accumulate in the cylinder.

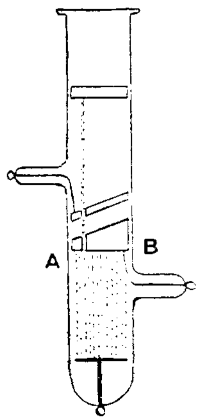
On the Method by which the Retrograde Rays acquire their Velocity.

We have seen that the velocity of those positive rays which move away from the cathode, and which are, when under observation, free from the influence of the electric field in the tube, is practically the same as that of the Canalstrahlen which have moved up to and then passed through the cathode. This result is remarkable, for in the latter case the action of the electric field which produces the discharge in the tube would increase the velocity of a positively charged particle, while in the former it would diminish it. The fact that the velocities in the two cases are very much the same suggests, at first, the suspicion that the electric field may not be accountable for any considerable portion of the velocity in either case, and that perhaps the particles forming these rays may, like the α particles given out by radioactive substances, start with a high initial velocity, much higher than they could acquire under the electric field. If we refer to the table of velocities given on pages 662–3, we shall see that there is not, in the different experiments, much variation in the velocity of the particles; these are always about 2×10^8 cm./sec., and could be generated by a fall through a potential-difference of about 20,000 volts. We must not, however, attach too much importance to the constancy of the velocity, for the range of pressure over which we can make accurate observations on the retrograde rays is very limited. For when the pressure gets very low, and the discharge requires a high potential-difference to send it through the tube, the rays are not bright enough to be observed; while if the pressure is more than a small fraction of a millimetre, the rays either do not reach the screen, or when they do reach it are so diffuse that the phosphorescent patch is not definite enough for its position to be measured with accuracy. And although even rough measurements show that at these high pressures the velocity of the particles is less than when the pressure is low, we should not be justified without further evidence in concluding that the initial velocity was less, for before reaching the screen the rays have had to make a long journey through the gas, and if the pressure is high, they will in their journey lose more of their velocity than when the pressure is low.

To test whether or not the velocity of the rays was due to the electric field, I tried the following experiments:—

In the first experiment, a piece of wire gauze was placed about 2 mm. in front of the perforated electrode of the tube represented in fig. 2 and well insulated from it; the gauze was used as the cathode and measurements of the velocity of the particles were made (1) when the perforated electrode was connected with the gauze, (2) when it was connected with the anode. In the second case, a particle if it retained its charge during the whole of its path, would in its journey between the gauze and the perforated electrode be at least as much retarded as it had been accelerated before reaching the gauze, and any velocity it possessed after passing through the perforated electrode must have been acquired from sources independent of the electric field; while in the first case its velocity would be measured by the electric field in the tube. On trying the experiment, it was found that though the Canalstrahlen were not nearly as bright in the second case as in the first, they were still quite perceptible, and that the velocity of those which got through was the same as the velocity of those reaching the screen in the first case. The fact that a large proportion of the rays are stopped by connecting the perforated electrode with the anode, while those which get through are not affected, shows that the velocity of the majority of them is not great enough to travel against the potential-difference between the electrodes; while the fact that some get through without diminution of velocity, indicates that when they are passing between the gauze and the perforated electrode, they are for the moment electrically neutral and without charge, and that they re-acquire, by losing a corpuscle, a positive charge after passing through the opening in the electrode by collision with the molecules of the gas. The following experiment shows in perhaps a simpler way than the preceding one that some of the Canalstrahlen are uncharged during a portion of their path. The perforated cathode (fig. 5) was wedge-shaped, the angle

Fig. 5.



of the wedge being about 27°, the diameter of the cathode was 2 cm., the aperture through which the Canalstrahlen passed was about 5 mm. from the sharp end, the length of the path of the rays from one side of the cathode to another was about 2·5 mm. A flat piece of wire gauze was fixed parallel to the upper face of the cathode (the face most remote from the anode), and insulated from it: the distance of the gauze from the cathode was about 3 mm. The Canalstrahlen travel at right angles to the lower face AB of the cathode. If the wire gauze is connected with the anode, and if the particles in the Canalstrahlen are charged, they will after passing through the cathode be acted on by a force which has a component at right angles to their direction of projection: thus if they are positively charged they will be bent to the right, if they are negatively charged to the left, while if they are uncharged they will be undeflected. The path of the rays when the pressure of the gas is not too low, can readily be traced by the luminosity they produce in the gas as they pass through it. On trying the experiment, it was found that when the gauze was connected with the anode the path of the few rays which got through the gauze was a straight line, coinciding in direction with their path before passing through the cathode. An easy way of seeing this is to connect by means of a key the gauze in quick succession with the anode and the cathode, when it is easily seen that though the Canalstrahlen are much more numerous in the latter case than in the former, the paths of those which do get through are identical, so that even when the gauze is connected with the anode some of the rays get through the space between *cd* and *cf* without suffering any deflexion, showing that they must be uncharged as they pass through this region. It is thus evident that a considerable number of the positively charged Canalstrahlen lose their positive charge by attracting when in the neighbourhood of the cathode a negatively electrified corpuscle; the mass of the corpuscle is so small in comparison with that of the particles forming the Canalstrahlen, that the addition of the corpuscle will not materially reduce the velocity of the Canalstrahlen. These rapidly moving uncharged particles will soon get ionized by collision, and by losing a negatively electrified corpuscle again become positively charged.

In my first paper on the positive rays (Phil. Mag. xiii. p. 561) I showed that at not too low pressures the appearance presented by the phosphorescence on the screen indicated that many of the particles in the Canalstrahlen were positively charged for only a portion of their path; the experiments just described are very direct evidence of this effect.

Again, at not too low pressures the Canalstrahlen are accompanied by negatively electrified particles having masses and velocities equal to those of the positive particles;

the negatively electrified particles in my experiments always being less numerous than the positive ones, in most cases very much so, in others the difference was not very great. We should expect the negatively electrified particles to be less numerous than the positive ones, since they would more readily lose their charges by collision.

I think that the positive rays which travel away from the cathode arise in the same way as the negative rays which accompany the Canalstrahlen. Let us consider what happens to the Canalstrahlen as they approach the cathode. When they reach the cathode some of them, as we have seen, get neutralized there, some will go further than this, and by gathering another corpuscle will become negatively electrified; those negatively electrified ones will, however, be repelled from the cathode, and under the action of the electric field will acquire a velocity of the same order as that acquired by the positive particles in their approach to the cathode. The rapidly moving electrified particles will in their course through the gas soon lose corpuscles by collision and thus become positively electrified, forming the positive rays which come from the cathode. Such rays, however, on the view just given start their journey with a negative charge.

The Canalstrahlen and the positive retrograde rays are not found with all types of discharge, thus in the type of discharge sometimes called the flash discharge: which occurs when a condenser of large capacity is earthed through the discharge-tube, the discharge passes as a column of uniform luminosity stretching from one electrode to the other, and there is no dark space in the neighbourhood of the cathode. In this case I have never been able to detect positive rays of any kind, either in front of or behind the cathode.

It is important to distinguish between the positive ions to be found in a gas, ionized by Röntgen rays and not exposed to electric fields strong enough to give to them very high velocities; and the positive ions which, like those in the Canalstrahlen, have very great kinetic energy. For between the positive charges and the molecules there are forces comparable in intensity to those which exist between the atoms of different elements having the greatest chemical affinity for each other. Thus, unless the positive ions possess more than a certain amount of kinetic energy, combination will go on with great rapidity and positively charged aggregates will be formed. If, however, the positive ions are moving with great rapidity, they will be in a state analogous to a gas at a very high temperature, and at these very high temperatures chemical combination does not take place. We have seen that the particles in the Canalstrahlen have a velocity of the order of 2×10^8 cm./sec. With a velocity such as this their kinetic energy would be equal to the mean kinetic energy of the molecules of a gas at a temperature of many hundred thousand degrees absolute; and though, as I have shown in 'Conduction of Electricity through Gases,' 2nd edition, p. 360, a positive ion might be expected to combine with a corpuscle if its velocity were but a little less than this, it would not be likely to do so with an uncharged molecule where the attraction would be very much less. If we take the case of a positive ion of mass m projected with a velocity V at right angles to the line joining it with a molecule of mass M, and at a given distance from it, the condition that the ion should be able to get away from the molecule is that

$$mV^2 \cdot \frac{M}{m+M}$$

should be greater than a certain quantity depending on the force between the molecules and the ion and the apsidal distance between them. Now if the force were independent of the mass of the molecule, we see that it would require a greater value of mV^2 to separate the ion from the molecule, when M is small compared with m, than when it is large. Thus if the kinetic energy of the ions were gradually to diminish say by collisions with the molecules, then if there were molecules of different masses in the gas through which the Canalstrahlen are moving, combination would occur first with the molecules of smallest mass, while the heaviest molecules would be the last to combine. The lightest molecules would thus have the first pick of the ions, which would therefore tend to be absorbed by the lightest gases. The force between an ion and a molecule is proportional to the volume of the molecule; and if the volume of a molecule were to increase as rapidly as its mass, the preceding considerations would not be valid. We have every reason, however, to believe that the changes in the volume of the molecules are not comparable with the changes in the masses: that, for example, the volume of a molecule of oxygen, instead of being sixteen times that of a molecule of hydrogen, is hardly more than twice, so that the increase in the forces exerted by the heavier molecules is not sufficient to counteract the influence of the increased mass.

The Nature of the Positive Ions in different Gases when the Ionization has settled into a steady state.

The Canalstrahlen are formed in very intense electric fields, and the kinetic energy which they possess tends to prevent them combining with the molecules and corpuscles around them; they are thus under quite different conditions from the ordinary ions produced in a region where the electric force is small or absent, for these have time before being removed from the field to enter into combination with the molecules, the system of molecules and ions getting into a steady state if the source of ionization is constant. The difference between this case and that of the Canalstrahlen may be compared with the difference between the state of a mixture of different chemical substances after they have entered into combination and settled into a state of equilibrium and when they were first mixed. I thought that it would be interesting to determine the values of e/m for the ordinary ions simultaneously with the determination of e/m for the Canalstrahlen in the same discharge-tube. The method used to determine e/m for the ordinary ions was as follows. A tube represented in

Fig. 6.

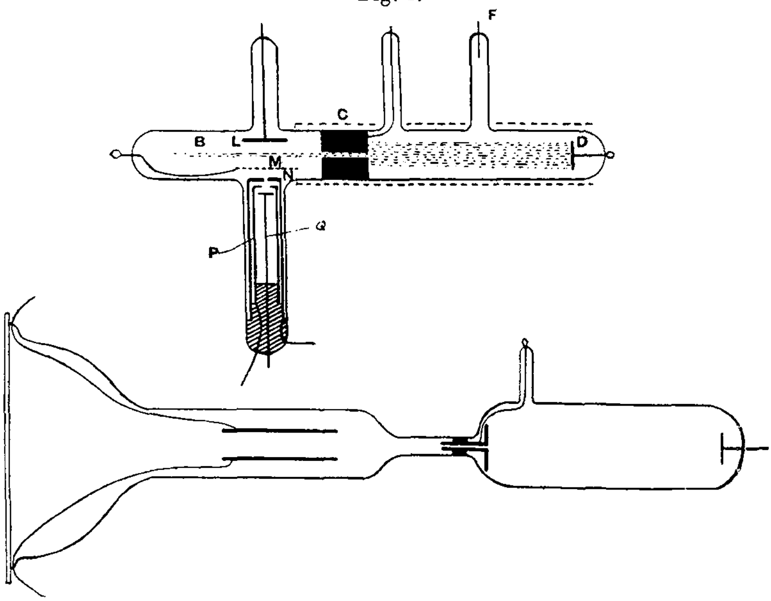


fig 6 was sealed on to the tubes such as have already been described in connexion with the determination of e/m for the Canalstrahlen. B is an ionization chamber, the gas in it being ionized by cathode rays coming down through the tube C which was connected with the earth. The cathode was at D in front of the tube, the anode in a side tube F. Three parallel electrodes, L, M, N, were put in the ionization chamber. The first, L, was a plate at the top of the tube ; the second, M, near the bottom of the tube was a piece of wire gauze about a millimetre above N, which was the top of an earth-connected cylinder, with a small hole ·9 mm. in diameter bored through the centre, the thickness of this plate was 1·6 mm. By means of these electrodes ions could be collected and some of them sent through the hole with a definite and known velocity. Suppose for example we wish to send a stream of positive ions through the hole. A small difference of potential (in our experiments generally that due to two Leclanché cells) was maintained between the plates L, M, L being at the higher potential. The electric field produced in this way caused a stream of slowly moving positive ions to pass downwards through the gauze ; by means of a potential divider any potential-difference between 10 and 800 volts could be established between the gauze and the top of the cylinder, the gauze being positive to the cylinder. The ions collected by the upper plates thus entered into a much stronger field which gave to them a velocity much greater than that with which they entered it, so that when they passed through the hole they were all moving with practically the same velocity.

Beneath the top of the box there was an insulated Faraday cylinder (P) connected with a Wilson electroscope. The distance between the top of the cylinder and the bottom of the plate was 1 mm. in one piece of apparatus, ·5 mm. in another ; the diameter of the hole in the Faraday cylinder was 2·3 mm. Beneath this hole there was a metal disk insulated and connected with another Wilson electroscope; the plane of the disk was parallel to N and thus at right angles to the undeviated path of the ions, the axis of the hole in N passed through the centre of the disk. The part of the tube below N was placed between the poles of a powerful electromagnet, the lines of magnetic force being at right angles to the undeviated path of the ions, and parallel to the direction of the cathode rays. To protect the cathode rays coming from D from the magnetic field, a deep cutting was made in one of the poles of the electromagnet and the portion from C to D of the tube placed in this and then covered over with layers of soft iron. This tube was sealed on to the tube T of the kind already described, for the determination of e/m for the Canalstrahlen.

If the ions travelled without deviation parallel to the axis of the tunnel in N, they would all strike against the disk Q, and the Faraday cylinder would not receive any charge. If, on the other hand, they were very much deflected by the magnetic field, they would all strike against the Faraday cylinder and the disk would not receive any charge. If we measure the charges received by the disk and the Faraday cylinder during any time, the ratio of the charges will be the ratio of the number of ions which strike against the disk to the number striking against the cylinder. The readings of the electroscopes do not give us directly the charges received by the systems to which they are attached, but the potentials to which these systems are raised. We can, however, if we know the ratio of the potentials easily deduce that of the charges. For let E_1V_1 be the charge and potential of the Faraday cylinder, E_2, V_2 the corresponding quantities for the disk.

Thus if the q's represent coefficients of capacity, we have

$$E_1 = q_1V_1 + q_{12}V_2$$
$$E_2 = q_{12}V_1 + q_2V,$$

so that

$$\frac{E_1}{E_2} = \frac{q_1V_1 + q_{12}V_2}{q_{12}V_1 + q_2V} . \qquad (1)$$

To determine the q's by experiment we proceed as follows. Given a charge to the disk, the cylinder being insulated and uncharged, then if V_1' and V_2' are respectively the potentials of the cylinder and disk as determined by their electroscopes,

$$q_1V_1' + q_{12}V_2' = 0, \quad \text{since } E_1 = 0.$$

Thus if α is the ratio of the potential of the cylinder to that of the disk when the cylinder is uncharged,

$$q_1 = -q_{12}\frac{V_2'}{V_1'} = -\frac{q_{12}}{\alpha}.$$

Similarly, if β is the ratio of the potential of the disk to that of the cylinder when the disk is uncharged, we have

$$q_2 = -\frac{q_{12}}{\beta}.$$

Substituting in equation (1) we have

$$\frac{E_1}{E_2} = \frac{\beta}{\alpha}\frac{(V_1 - \alpha V_2)}{V_2 - \beta V_1}.$$

The quantities α and β are very easily determined, and from this equation we can deduce the ratio of the charges when we know that of the potentials. By using two electroscopes and determining by means of them the *ratio* of the charges received by the cylinder and disk, we eliminate any irregularities that might arise from variations in the working of the coil used to produce the cathode rays which ionize the gas in the ionization chamber.

If an ion is projected through the tunnel in N along the axis of the tunnel, it will, if there is no magnetic field acting iupon it, travel along a straight line and hit the disk. If there s a magnetic field its path, after getting through the hole, will be a circle, since if it is free when once it has got through the hole from any electric force, it will, however, continue to hit the disk until the radius of this circle is less than the radius of the circle passing through the hole, the edge of the disk, and touching at the hole the axis of the tunnel. If d is the distance of the disk below the hole, a the radius of the disk, r the radius of this circle is equal to $\frac{d^2+a^2}{2a}$. When the radius of the path of the ion is less than this, the ion will give up its charge to the Faraday cylinder; when it is greater than this it will give up its charge to the disk.

If H is the magnetic force acting on the ion, e its charge, m its mass, and r the radius of its circular orbit,

$$\mathrm{H}er = mv,$$

if V is the potential-difference between the gauze and the top of the box

$$\mathrm{V}e = \tfrac{1}{2}mv^2;$$

thus

$$\mathrm{H}^2r^2\frac{e}{m} = 2\mathrm{V}.$$

Thus when H increases through the value given by the equation

$$\mathrm{H}^2\left(\frac{d^2+a^2}{2a}\right)^2\frac{e}{m} = 2\mathrm{V}, \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

there ought to be a large increase in the ratio of the charge on the Faraday cylinder to that on the disk. If the pencil of ions coming through the hole were indefinitely thin, and if all the ions travelled with the same velocity in the same direction, the transference of the charge from the disk to the cylinder would be quite abrupt. With a magnetic force less than a certain value, all the charge would be on the disk, while with a force greater than this all the charge would be on the cylinder. In my experiments the diameter of the hole, ·9 mm., was a considerable fraction of the length 1·6 mm. of the tunnel, so that there was a considerable latitude in the direction of propagation of ions through the hole. This has the effect of making the ratio of the charges on the cylinder and disk change much less abruptly than if they were all projected in the same direction, since those ions which are projected towards the side of the cylinder to which they are bent by the magnetic field, will be carried to the side by a smaller magnetic force than those which are projected at right angles to the disk. When the hole is very small, the charge carried by the ions passing through it in a given time is also very small, and the potentials of the disk and cylinder change very slowly. The purpose for which these experiments were made was not so much to get accurate values of e/m for the ions as to find out whether these had masses comparable with the mass of an atom of hydrogen, or of oxygen, &c. The arrangement used was adequate for doing this, and had the advantage of giving a supply of ions which could produce measurable effects in a minute or so, thus avoiding many difficulties as to insulation which crop up when the experiments have to be extended over very much longer periods. Experiments with very much smaller holes are, however, in progress.

The strength of the magnetic field between the poles was determined by comparing the currents induced in a small coil when suddenly withdrawn from the magnetic field with the current obtained by turning an earth inductor through 180° in the earth's magnetic field. When the pole-pieces were 1·15 cm. apart, the magnetic forces H for different currents through the coils of the electromagnet were as follows :—

Current through Electromagnet in amperes.	H.
·5	1330
1	2570
2·5	4000
2	4900
2·5	5600
3	6000
3·5	6400
4·0	6660

When, as in our Faraday cylinder, $d=5$ mm. $e=2$ mm., the radius of the critical circle $\frac{d^2+a^2}{2a}=\cdot 725$ mm., we see by the application of equation (2) that if $e/m=10^4$, the potential-difference V required to reduce the radius of the orbit to the critical value would, when the currents through the electro-magnets were 1, 2, 3, 4 amperes, be respectively 170, 620, 900, 1100 volts. These are the potential-differences between the gauze and the top of the cylinder N required to send the ions to the plate. The following table gives the charge acquired by the disk when the sum of the charges on the disk and Faraday cylinder was 100 for different strengths of magnetic fields; assuming that all the ions carry the same charge, these numbers represent the percentage of the ions passing through the hole which reach the disk. In the table V is the potential-difference between the gauze and N in volts, ι the current through the electromagnet in amperes, and n the percentage of ions which reach the disk. The gas in the tube was hydrogen.

	V=10.	V=20.	V=30.	V=40.	V=50.	V=60.	V=80.
ι	n	n	n	n	n	n	n
1......	17	18·4	18	18	18	19	22·8
2......	18	23	23	22	22	20	19
3......	11	16	22	23	25	26	21
4......	8	9	20	22·5	25	27	26

	V=100.	V=120.	V=140.	V=160.	V=180.	V=420.
1.....	23	25	24	28	31	50·5
2.....	16	17	22	14	12	12
3......	21	19	19	16	9	9
4......	25	23	21	18	15	8

On looking at the numbers we see that until the voltage exceeds 160 volts there is no appreciable difference between the number of ions going to the disk when the magnetic field is due to a current of 1 ampere, and when it is due to 2 amperes. We saw, from the preceding calculation, that a voltage of 170 volts would carry ions for which $e/m=10^4$ to the disk against the electric current, while it would require about 700 volts to drive them across when the current was

2 amperes, thus the difference which sets in between the results when $\iota=1$ and $\iota=2$ at 160 volts indicates the presence of a considerable number of ions for which $e/m=10^4$.

For voltages between 30 and 160 there is no appreciable difference with currents ranging from 1 to 4 amperes, while for voltages less than 30 there is an appreciable diminution in the number which get to the disk when the current through the electromagnet is raised from 1 to 4 amperes. This indicates that there are some ions which, under a voltage of say 25 volts, are stopped when the magnetic field is that due to 4 amperes, but can get across when it is due to 2 amperes. Since 1100 volts would just drive particles for which $e/m=10^4$ across the field due to 4 amperes, 25 volts will drive particles for which $e/m=10^4/(1100/25)=10^4/44$ across this field. For the field due to 2 amperes 620 volts are required to drive particles for which $e/m=10^4$, 25 volts will drive particles for which $e/m=10^4/(620/25)=10^4/25$. From the preceding results we infer the presence of ions for which e/m is between $10^4/44$ and $10^4/25$. Such ions might be molecules of nitrogen or oxygen due to traces of air in the discharge-tube; these, however, are only a small fraction of the whole number of ions. The pressure of the hydrogen in this case was about ·003 mm. It is necessary to work at pressures so low that the mean free path of the ion is large compared with the distance d.

Let us now compare the results obtained when the apparatus had been repeatedly filled with oxygen obtained by heating permanganate of potash in a tube fused on to the discharge-tube, running the coil with the gas at the pressure when the discharge passes most easily, and then filling and repumping; the oxygen on its way from the permanganate to the discharge-tube went through a worm immersed in liquid air to free it from any traces of water vapour given off from the permanganate. No hydrogen lines could be detected in the spectrum. The Faraday cylinder had been taken down between this experiment and the preceding one, and slightly altered so that the radius of the critical circle in this case when $d=4$, $a=2{\cdot}5$, is ·47 cm., hence the potentials required to force ions for which $e/m=10^4$ across to the disk when currents 1, 2, 3, 4 amperes flow through the coils of the electromagnet are respectively 72, 270, 400, and 480 volts. The pressure of the oxygen was ·009 mm.

The following are the results of the experiments, n as before being the percentage of ions which reach the disk :—

	V=10.	V=15.	V=20.	V=25.	V=30.
ι	n	n	n	n	n
1.........	75	82	81	81	80
2.........	56	62	68	72	72
3.........	36	43	50	58	61
4.........	28	27	43	50	56

	V=40.	N=100.	V=200.	V=300.	V=400.
1.........	82	81	81	81	81
2.........	78	80	80	80	81
3.........	68	78	76	79	80
4.........	63	76	79	80	80

The figures in this case are quite different from those for hydrogen. We see that for voltages over 100 the charge on the disk is not appreciably diminished when the current through the electromagnet is raised from 1 up to 4 amperes; this shows that the number of ions with masses comparable with those of a hydrogen atom is too small to be detected, for such ions under a field of 100 volts would have been able to make their way to the disk against a magnetic field due to 1 ampere, but not that due to 2 amperes or more; thus if these had been present in any considerable number, the number reaching the disk when $\iota=1$ would have been appreciably greater than when $\iota=2$.

The fact that 20 per cent. under these voltages reach the Faraday cylinder is due, I think, to the obliquity of the ions as they come through the hole, and to the diffusion they suffer in passing through the gas. Under the smaller voltages the effect of the magnitude of the magnetic field is very apparent; thus until the voltage is above 20 the majority of them are stopped by a field of 4 amperes, indicating that the mass of the majority of the ions is not greater than 480/20 or 24 times the mass of an atom of hydrogen. In fact that the majority of the ions have masses comparable with that of the molecule of oxygen, and are not aggregates of several molecules.

Though the preceding list shows that the number of ordinary hydrogen ions in this gas was too small to be detected, yet when the Canalstrahlen produced in a tube in direct connexion with the one in which the ionization occurred were investigated they were found to be well developed, and to give exactly the same value for e/m as when the apparatus had been filled with hydrogen, as in the experiments discussed on pages 678, 679.

By measuring the relative numbers of ions carried to the cylinder and the disk by different voltages against a constant magnetic field we can readily estimate the relative amounts of heavy and light ions in the gas. Indeed I think that by using a very small hole in the plate N a very fair analysis of the gas in the ionizing chamber might be made. Thus suppose the magnetic field were that due to 3 amperes through the coils of the electromagnet; then with apparatus of the dimensions used in one of the experiments the ions for which $e/m=10^4$ would not reach the disk until $V=900$, while those for which $e/m=\frac{1}{2}10^4$ would reach it when $V=450$, those for which $e/m=\frac{1}{16}10^4$ when $V=56$, those for which $V=\frac{1}{32}10^4$ when $V=28$. Thus for ions of different atomic weights the stages are well separated, and the relative numbers of the ions of the different kinds could be determined. With the comparatively large hole used in the experiments described above it was quite easy to observe the gradual diminution in the number of the lighter ions, as each dose of oxygen was supplied to the tube and then pumped out. This method of analysis is applicable at pressures far below those at which even spectrum analysis is available.

By reversing the potentials in the ionization chamber we can collect and send through the opening in the plate negative ions and corpuscles which are present in large numbers in the gas. The corpuscles, on account of their small mass, are prevented from reaching either the Faraday cylinder or the disk by a comparatively small magnetic force, and then only negative ions get through to the conductor. The proportion of these reaching the disk and cylinder with changes in the electric and magnetic fields show variations of a similar character to those observed for the positive ions.

The relative rates at which the cylinder or disk charged up according as positive or negative ions were supplied to them from the ionization chamber was determined. When the magnetic field was weak the rate of charging was much more rapid with negative than with positive ions; this was due to the excess of corpuscles in the ionization chamber; when, however, the magnetic field was strong enough to stop the corpuscles, the rate of charging under potential-differences of the order of about 200 volts was about the same for the negative as for the positive ions, while with smaller differences of potential, say 25 volts, the rate of charging with negative ions was only about 1/6 of that with positive. The positive ions seem, in the ionization chamber, to be moving more rapidly than the negative, for with no electric field in that chamber both cylinder and disk acquire a positive charge when the magnetic field is strong.

With the apparatus we have been describing we can measure simultaneously the values of e/m for the ions and the Canalstrahlen in the same vessel, and the experiments we have described show that we can get a complete change in the character of the ions without any change in the nature of the Canalstrahlen; this is, I think, strong evidence that the particles composing the Canalstrahlen are the same from whatever source they may be derived.

It might, however, be urged that although the tube might be cleared of hydrogen to begin with, this gas might be driven by the discharge out of the cathode and that this might be the source of the Canalstrahlen, and I have noticed a phenomenon which at first sight suggests this view. I have observed that under some conditions there is a lag amounting in some cases to half a minute or so between starting the discharge and the appearance of the phosphorescence due to the canal-rays; this might be explained by supposing that it takes time to liberate sufficient hydrogen to produce appreciable Canalstrahlen. I have made many experiments on this lag and these show that it has no special connexion with hydrogen, but is due to an alteration in the pressure of the gas produced by the discharge. It is well known that the Canalstrahlen are only well developed when the pressure in the tube is between certain limits. It is only when the initial pressure is near to, but outside, one of these limits that the lag occurs, and then the alteration in pressure which occurs when the discharge passes may accumulate until the pressure is brought within the required limits. That this, and not the introduction of hydrogen rather than any other gas, is the explanation of the lag is I think proved in the following experiments:—If the presence of hydrogen were all that is wanted for the Canalstrahlen, then the lag should not occur when the tube is filled with hydrogen: we find that the lag occurs when the tube is filled with hydrogen, as well as when great precautions have been taken to remove this gas from the tube. Again, in a tube from which hydrogen has been removed and the lag is well developed, the admission of a small quantity of dry air will remove the lag just as effectively as the admission of hydrogen. When once the lag has been got rid of it is necessary to give the tube a long rest from the discharge before it returns. The fact that the lag may be destroyed by admitting a small quantity of gas shows that it is due to the alteration in pressure and not to a change produced by the discharge in the surface of the electrode. This can also be proved in the following way: two discharge-tubes A and B are connected together and with the pump, and the pressure is adjusted so that both A and B show the lag; then if the discharge is sent through A until the lag disappears from that tube, it will be found to have simultaneously disappeared from B, though no discharge has been running through this tube.

It is somewhat remarkable that we do not, when the tube is filled with oxygen, get any trace in the Canalstrahlen of particles having masses comparable with those of the ions in oxygen. For though such ions would not be formed in very intense electric fields, there are places in the discharge-tube where the electric field is weak, as, for example, outside the cathode dark space; we might expect positive ions to be formed in these regions, and then dragged by the electric field up to and through a perforated cathode mingling with the Canalstrahlen. The reason that we get no evidence of these oxygen ions in the Canalstrahlen is, I think, as follows: Let A be a positive ion, B a corpuscle, and let the relative velocity of A and B at the instant under consideration be at right angles to AB and equal to V. Then it is easy to show that A and B will not part company if $\frac{mV^2}{2}$ is less than $\frac{e^2}{AB}$, where m is the mass and e the charge of the corpuscle, M the mass of the ion being supposed very large compared with m. Thus if the relative velocity falls below a certain value the ion and the corpuscle will form a neutral doublet and will cease to be a possible constituent of the Canalstrahlen. If the ion is moving much more rapidly than the corpuscle, then V will be the velocity of the ion, and we see that the smaller this velocity the more likely is it to have its charge neutralized. M being the mass of the ion $\frac{1}{2}MV^2 = Pe$, where P is the potential-difference moved through by the ion, thus the ion will be neutralized unless $P > \frac{M}{m} \cdot \frac{e}{AB}$. Thus to protect a heavy ion, for which M_1 is large, from being neutralized it must be subject to a much stronger electric field than would be necessary for a light ion; thus, if there were a mixture of different gases in the discharge-tube, the ions formed from the lighter gases would persist longer than those formed from the heavier ones.

An illustration of this result is furnished by the fact that, as I showed in the paper (Phil. Mag. ser. 5, vol. xiii. p. 561), the only ions besides those of hydrogen which can be observed in the Canalstrahlen are those of the next highest gas helium, which, when the discharge passes through helium, can be observed in the Canalstrahlen without difficulty.

The places where the neutralization of the positive ions by the corpuscles takes place will be either quite close to the cathode or when the cathode is perforated in the region behind the cathode; for in front of the cathode where the positive ions are produced, though the velocity of these ions will be small, since they are in a feeble electric field, yet the corpuscles which have come from the cathode will have passed through a great potential-difference and will have a very high velocity; thus the relative velocity of the positive ions and the corpuscles will be very large. Quite close to the cathode the velocity of the corpuscles will be very small, and though the velocity of the ion will be much greater than in the former case, yet since the mass of the ion is so much greater than that of the corpuscle, the velocity acquired by the ion under the same potential-difference will be small compared with that acquired by the corpuscle, so that the relative velocity of the two close to the cathode will be much less than at a greater distance in front of it, so that combination is much more likely to occur near to the cathode, or if the cathode is perforated behind it.

If the forces between a small positive ion and an uncharged molecule are independent of the atomic weight of the molecule, or only increase slowly as the atomic weight increases, then such an ion is more likely to attach itself to a light molecule than to a heavy one; for we can show that the condition that the ion and the molecule should separate is that

$$\frac{M M' V^2}{M+M'}$$

should be greater than a certain quantity depending only on the force between the systems and their distance apart when nearest together. M is the mass of the ion, M′ that of the molecule, and V the relative velocity of the two at the absidal distance. If M′ is very large compared with M the condition is that Mv^2 should be greater, while if M′ were equal to M, the condition is that $\frac{1}{2}Mv^2$ should be greater than the same quantity; thus in the second case the ion would take twice as much energy to get free as in the first, and so would be more likely to combine with the molecule.

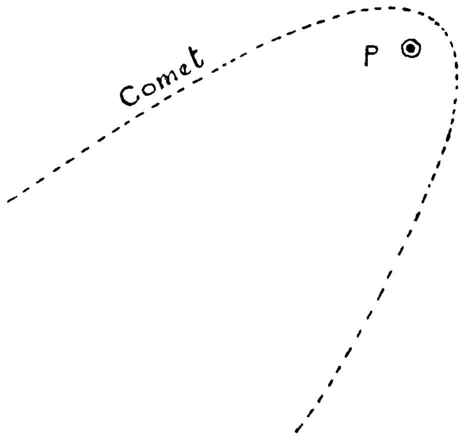
Nature of Ionization by Cathode Rays.

If, as seems most probable, the positively charged particles are produced from the ionization of the gas by cathode rays, the study of the processes by which this ionization is accomplished may be expected to throw considerable light on the nature of the positive rays. When a gas is ionized by cathode rays, secondary cathode rays are generated, and the author has recently shown (Proc. Camb. Phil. Soc. xiv. p. 540, 1908) that the maximum velocity of the secondary rays is independent of the velocity of the primary rays. A comparison of the velocity of the secondary rays from gases, as determined in my experiments, with those from metals, measured by Füchtbauer (*Phys. Zeits.* vii. p. 748, 1908) shows that there is not much difference between the two. The velocity of the rays from gases was that due to a potential-difference of 40 volts, of those from metals that due to a potential-difference of 33 volts; the difference between these results is not greater than could be explained by errors of experiment. Thus, as far as our present knowledge goes, the velocity of a secondary cathode ray is independent both of the velocity of the primary ray and varies but little with the nature of the molecule from which the secondary ray is projected. The first result shows that the energy of the secondary ray is not acquired by a corpuscle in the primary rays striking against one in a molecule of a gas and imparting to it sufficient energy to force it out of the molecule, for if this were the case we should expect the energy of the secondary ray to vary quickly with that of the primary. Neither does it seem likely that the energy in the secondary ray is due to a general explosion of the molecule of the gas produced by a gradual accumulation of energy in the molecule from impacts with the primary rays, for then we should expect the energy in the secondary rays to depend largely on the chemical nature of the molecules.

As a working hypothesis to account for these very striking properties of the secondary rays I would suggest that perhaps the first stage is ionization by cathode rays, may be the separation from the molecule, not of a single corpuscle, but of an electrically neutral doublet consisting of a negatively electrified corpuscle in rapid rotation round a much more massive particle with a positive charge, and that these doublets may be the same from whatever molecule they may be ejected. The secondary cathode rays are due to the subsequent breaking up of this doublet, their energy being the kinetic energy possessed by the corpuscle when rotating round the positive charge. This hypothesis would also explain the constancy of e/m in the Canalstrahlen produced from different gases.

There are many ways in which the doublet might get broken up after it had escaped from the molecule. Thus, for example, if another corpuscle, which we shall call for brevity a comet, were under the attraction of the positive particle to describe an orbit such as that shown in fig. 7,

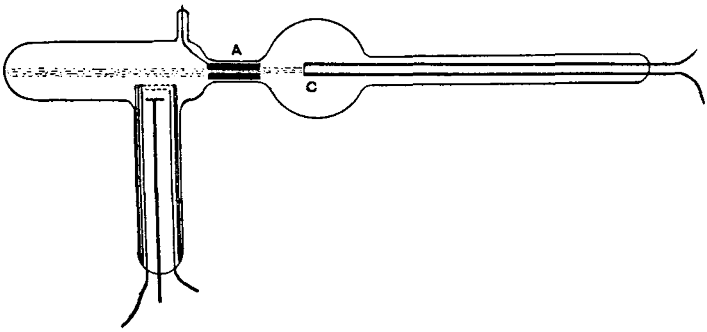
Fig. 7.



then when the comet was in the immediate neighbourhood of the positive particle, it would neutralize the attraction of this particle on the corpuscle in the doublet; thus this will move off with undiminished velocity along a straight line, and when the comet has left the system, will, if not free, be at any rate further from the positive particle than it was before, and still possessed of its original kinetic energy; if it did not get free under the influence of the first comet, a repetition of the process by other comets might liberate it from the doublet. The same effect might be produced if the positive part of the doublet came close to a gaseous molecule, which behaved like a conductor of electricity; the negative charges induced on the conductor would balance the attraction of the positive particle on the corpuscle in the doublet, and just as in the previous case, the corpuscle would be able to get off with undiminished velocity.

The questions now arise, can we get any experimental evidence of the existence of these doublets, and is it possible that such systems, if they existed, could have escaped the careful scrutiny which has been given? The second question is more easily answered than the first, for these doublets being uncharged would not possess the properties which make the positive rays or the cathode rays so noticeable; thus they would not be deflected by uniform magnetic or electric fields, and the absence of the charge might involve also a loss of the power of producing luminosity when they pass through a gas, and thus render them invisible. With regard to the first question I have made some preliminary experiments, the results of which suggest the existence in the neighbourhood of cathode of neutral systems, such as the doublets which dissociate into corpuscles and positive ions. The arrangement used in these experiments is represented in fig. 8.

Fig. 8.



The idea of the experiment was as follows:—If the secondary cathode rays are produced from the primary without the intervention of the neutral doublet stage, then, as the secondary ionization is due to the secondary cathode rays, a strong electric field, arranged so as to stop the negative corpuscles forming the secondary cathode rays, ought to act as a complete screen against this ionization. If, on the other hand, there is an intermediate stage between the primary and secondary rays, and if this stage consists of neutral doublets, then some of these ought to be able to get through the strong electric field, if this is quite close to the primary rays, because it is only those secondary rays which are produced from the doublets whilst the latter are passing through the field which would be stopped; the doublets themselves will not be stopped, and if they last long enough to get through the field they ought to give rise to ionization on the other side. To test this view the apparatus represented in fig. 7 was used. A copious supply of slowly moving primary cathode rays was produced from the hot Wehnelt cathode C, these passed through a hole in the anode A, the anode was earthed, the primary rays passed over the top of the side tube, T; across the top of the tube were stretched two parallel pieces of wire gauze about a millimetre apart: the upper gauze was earthed, the other could be charged negatively by connecting it with the negative terminal of a battery of small storage-cells, the positive terminal of which was earthed. When the lower gauze was earthed as well as the upper, the tube was filled with the glow due to the secondary rays. When the lower gauze was charged to a negative potential of about 40 volts, this glow became exceedingly faint; but that the gas below the gauze was ionized was shown by the fact that when the negative potential of the lower gauze was increased to about 200 volts, a potential quite insufficient to produce luminosity in an unionized gas, the tube again became full of luminous glow. Thus something capable of ionizing the gas was able to traverse the strong electric field. There are two sources of ionization which have to be eliminated before we can assign this ionization to the existence of neutral systems traversing the electric field,—the ultra-violet light coming from the luminous discharge in the main tube, and soft Röntgen rays produced by the slowly moving primary cathode rays. To test whether it was due to ultra-violet, a thin plate of quartz was placed over the top of the upper gauze: with this arrangement no luminosity could be detected in the side tube under the conditions as to potential and so on which gave bright luminosity in the tube when the quartz was absent. Hence I conclude that the luminosity was not due to ultra-violet light. To test whether it was due to soft Röntgen rays, taking the quartz away, I got a bright luminosity in the side tube with the primary rays passing horizontally down the tube, then by means of a magnet I bent the primary rays so that they struck the glass of the tube just above the side tube, the path of the rays being represented by the dotted line of the figure. This made the rays themselves further from the side tube, but brought the places where they struck the glass, the sources of the Röntgen rays, much nearer to that tube; so that if the ionization in the side tube were due to Röntgen rays it should be increased by the introduction of the magnet, while if it were due to the neutral doublets it would be diminished. As a matter of fact the luminosity in the side tube almost disappeared when the rays were deflected in this way, showing that it was not due to Röntgen rays, while the effect is what we should expect if the ionization were due to uncharged systems.

In the preceding experiments there is the possibility that the ionization might arise in some such way as the following. The secondary cathode rays would have to penetrate some way between the two pieces of gauze before they were stopped, and if they collided against the molecules of the gas they might ionize it: the positive ions so produced would, under the action of the electric field between the pieces of gauze, acquire considerable kinetic energy when they reached the lower gauze, they would travel some distance after passing through before they were stopped and brought back to the gauze, and would thus have an opportunity of ionizing the gas below the gauze by collision. The negative corpuscles produced in this way would be repelled from the lower gauze and might acquire sufficient energy to produce fresh ions by collisions, and thus give rise to the luminosity observed below the gauze. To eliminate this source of ionization, a strong magnetic field was used to prevent any of the secondary cathode rays from straying into a region where they could affect the ionization in the region under observation. Two arrangements were used for this purpose. In the first, the tube with the hot lime cathode (fig. 8) was used. The primary cathode rays were coiled up into a small bunch by means of a strong electromagnet placed just under the tube, from which the cathode rays emerge, the cathode rays in the early part of their path were screened from the effect of the magnetic force by thick iron plates. The magnetic force was strong enough to prevent the primary cathode rays, which were produced under a potential difference of about 250 volts, from travelling more than 2 or 3 millimetres across the lines of force. The path of the rays when not under the influence of magnetic force never approached within this distance of the two pieces of gauze, and the deflexion of these rays by the magnet was away from the gauze. No luminosity could be seen close to the gauze next to the discharge-tube. Nevertheless, when the lower gauze N was at a potential of about 200 volts, the upper gauze being earthed, there was a perceptible luminous discharge in the side tube, showing that in spite of the strong magnetic field something must have passed across the gauze and ionized the gas in the side tube. A modification of this experiment was tried, in which the two pieces of gauze were connected together and with the earth, and an insulated plate connected with a charged electroscope was placed in the side tube at some distance from the gauze; the ionization in the side tube produced a leak of the electroscope. It was found that even when the primary cathode particles were coiled up by the strong magnetic field into a small bundle at the mouth of the tube from which they emerge, there was a rapid leak of the electroscope showing that the gas in the side tube was ionized. The leak was more rapid when the electroscope was positively than when it was negatively charged.

A somewhat similar experiment was also tried with the apparatus represented in fig. 6. A magnetic field of 1200 was established between the pole-pieces, and the plates L, M, N connected with the earth, so that there was no electric field in the ionizing vessel. Under these circumstances neither the cylinder nor the disk received any electric charge when the electric discharge passed through the upper tube. The Faraday cylinder was then disconnected from the electroscope and charged up positively to about 40 volts; the disk now acquired a positive charge, when the cylinder was charged to -40 volts the disk got a negative charge. This shows that the gas between the cylinder and disk was ionized, though the magnetic field prevented any negative corpuscles from entering this region.

Though we have given reasons for thinking that the Röntgen rays are not the cause of the ionization in the side tube when this is exposed to strong magnetic fields, soft Röntgen rays are produced by the impact of the primary cathode rays against the molecules of the gas in the tube. This was proved by covering the end of the side tube (fig. 8) with thin aluminium foil and placing in the side tube behind the foil an insulated metal plate connected with a charged electroscope. The escape of electricity from this plate could not be ascribed to ionized gas making its way from the main tube into the side one, for the only channel of communication was through a long stretch of glass tubing from the main tube to the pump, and then through another long tube from the pump to the side tube; since the opening between the main tube and the side tube was closed, it was necessary to exhaust them separately. When the primary and secondary cathode rays were well developed and the main tube filled with a bright glow, the charge from the electroscope rapidly leaked away whether it were positive or negative. The gas in the side tube is thus ionized by rays which have passed through the thin aluminium foil. The leak was, however, completely stopped when, by means of a strong magnetic field, the primary and secondary cathode rays were rolled up into a small bundle at the mouth of the tube, from which they emerge just above the aluminium foil. In this case the length of the path of the rays after coming through the tube was only 2 or 3 mm., and there was hardly any luminosity in the tube. The aluminium foil prevents the ionization in the side tube in this case, for if the foil is removed the gas, as we have already stated, is ionized.

The preceding experiments are in harmony with the view that neutral doublets are one of the stages in the process of ionization; they must, however, be regarded as only preliminary. More extended experiments are necessary before we can be certain that the effects are not due to some very easily absorbed kind of radiation or to the diffusion of very slowly moving ions.

We have hitherto considered the case when the primary ionization was due to cathode rays, but there are reasons for thinking that similar doublets are produced when the ionization is produced by positive rays. Thus Füchtbauer (*loc. cit.*) found that the velocity of the secondary cathode rays from metals was the same whether they were produced by cathode rays or Canalstrahlen. It is sometimes argued that the much greater difficulty experienced in saturating a gas ionized by α particles than one ionized in any other way, shows that results of ionization are different in the two cases: this result is, however, exactly what we should expect if there were no such difference. For when a gas is ionized by α rays, each α particle produces an enormous number of ions, but there are comparatively few particles, and these are widely separated. Thus in a gas ionized by α rays we have intense ionization in some localities and very weak ionization in others, while other methods give much more uniform ionization. Now the electric force required to saturate a gas depends upon the maximum density of ionization as well as upon the average; thus it will require a more intense field to saturate a gas ionized by α particles than a gas where the total ionization is the same but the ionization is uniformly distributed through the gas. The researches of Moulin (*Le Radium*, t. v. March 1908) on the ionization by α rays, show that the differences between this kind of ionization and others can be explained as arising from the want of uniformity in the distribution of the α ionization.

I have much pleasure in thanking Mr. E. Everett and Mr. G. W. C. Kaye for the assistance they have given me in this investigation.